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Final report

Small research and development activity

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2 Executive summary

Terminalia catappa (Bislama Name – Natapoa), or tropical almond, has been identified as an excellent agroforestry tree species for Vanuatu and similar areas of the humid tropics and subtropics. Natapoa has been identified by the Vanuatu Department of Forests (DoF) as a priority plantation and reforestation species. Natapoa produces edible nuts, medicines and timber. Whilst the timber from mature trees is highly regarded in Vanuatu, there is currently very little information in the scientific literature on the growth potential, silvicultural management or on basic wood properties from plantation grown trees.

This species has much to offer growers of agroforestry systems, and is widely accepted across the Pacific as a tree that warrants further development; however, the extent to which the plantation grown wood can be considered a high value hardwood remains largely unknown. The objective of this small research activity was to assess growth and wood quality from three stands of planted *Terminalia catappa* (Natapoa) in Vanuatu. The data collected on growth and wood properties was used to develop information for landowners interested in planting high value timber trees. The data will also be used to write scientific conference presentations and papers.

The assessment of growth of Natapoa trees aged 3 to 12 years was conducted across five sites located on Espiritu Santo and Efate. The study assessed the growth performance of over 400 trees, and found the species to be rapidly growing, particularly on well managed sites. The average trees from 8-12 years old were growing at 2-3 cm in diameter per year up to 12 years old. However, the straightness of the trees stem (stem form) was adversely affected by the damage from shoot boring caterpillars.

Evaluation of wood properties across three sites was undertaken, two on Espitiru Santo Island (at IFP and Fanafo- Jubilee farm), and one site on Efate (Tranut- Teouma), from known-age planted Natapoa trees. The preliminary evaluation of wood density and heartwood formation was undertaken on 62 trees. The collection of wood cores, stem discs and sawn timber from six harvested trees also provided over 200 wood samples for analysis. The wood cores and larger wood samples allowed the evaluation of wood density across a wide range of ages and provenances (basic density and heartwood/ sapwood ratio). Wood density is a key parameter that is of importance to processors and end users. The results of this study showed that wood from young planted trees has a similar density to that of mature trees.

The priority wood properties that were determined were density (Green, air dried and basic) and heartwood/ sapwood ratios where possible. Trees of 12 years of age were found to have a mean basic density of 470 kg/m^3, which is in keeping with the density of mature wood from the published literature. The air dried density (at 12% moisture content) for wedge samples was 535 kg/m^3.

The colour and figure of this species is also of interest to those who may process the wood or make furniture from planted Natapoa trees. The wood from the sample trees indicated a wide variation in sapwood formation, colour, from very pale to dark brown.

While there were variations in wood density across age, sites and provenance; those variations were found to be similar to those of mature forest trees. The variation in wood colour and heartwood formation has a breeding and selection benefit, as superior individuals and provenances that have the most desirable wood properties can be selected. The results of the study have been used to produce extension materials, inform the development of a scientific conference presentation and will form part of the data in a scientific paper. The results will help to provide data to inform silvicultural management, utilisation and economic modelling for this important high value agroforestry species.

3 Introduction

Terminalia catappa (Bislama Name – Natapoa), or tropical almond, has been identified as an excellent agroforestry tree species for Vanuatu (VDoF 2012) and similar areas of the humid tropics and subtropics (Thompson and Evans 2006). Natapoa has been identified by the Vanuatu Department of Forests (DoF) as a priority species. Fortunately, a stand of the species was established at Shark Bay in 1999 by the AusAID funded SPRIG project. This trial brought together fourteen provenances from across Vanuatu to determine the nut quality and growth performance.

Natapoa produces edible nuts, medicines and timber. Whilst the timber is highly regarded in Vanuatu (Tungon pers comm 2012), the wood properties of the species are not well known. The potential benefit of this multi-purpose species in agroforestry systems is widely accepted across the Pacific (Thompson and Evans 2006); however, the extent to which the plantation grown wood can be considered a high value hardwood remains unknown. Despite the potential of this species, there is currently very little information on the growth potential, silvicultural management or on basic wood properties from plantation grown trees. Literature searches in Web of Science yields 141 references on the species by name alone, mostly on chemical properties of nuts, but no references at all when combined with the term “silviculture”.

Indigenous nut trees have been an important part of complex arboriculture, agriculture and socio-biological systems across the South Pacific (Evans et al 1994). The importance of nut trees in the South Pacific is destined to increase as the region experiences rapid growth in population, urbanisation and increasing demand for income diversification. Planting of tree crop species, such as Natapoa, in reforestation programs, has the capacity to deliver a diverse range of goods and services, including timber, food security outcomes and a broad range of ecosystem services; biodiversity conservation, maintaining water quality, mitigating flood damage and carbon sequestration. Whilst many of these benefits have tangible direct economic values, timber production is of particular interest for developing economies as it can provide a much needed source of foreign exchange. The wood of Natapoa is important traditionally, and is used in the building of canoes and artefacts (Walter and Sam 1994).

Diminishing wood supplies from natural forest have caused a reduction in the use of local hardwoods timber, especially in construction in Vanuatu (Virananmagga et al 2012). Under these conditions whitewood has been replaced by imported radiata pine (*Pinus radiata* D.Don) from New Zealand and Caribbean pine (*Pinus caribaea* Mor.) from Fiji. The development of plantations for construction and furniture timbers has been given a very high priority under the Vanuatu National Forest Policy (VNFP).The development of lesser-known native species for agroforestry systems has been the focus of many ACIAR projects in the Pacific region. Natapoa has been included in on-going trials in Vanuatu by the Whitewood Silviculture Project (FST/2005/089), that began in 2007, and the Whitewood Utilisation Project (FST2012/042). These projects have established research trials and demonstration plantations that include Natapoa in mixed species plantings.

The aim of this Small Research Activity (SRA) is to examine the growth and wood properties from this promising species. The objectives and activities of the research are to assess growth and wood quality from three stands of planted Natapoa (*Terminalia catappa)* in Vanuatu across age classes and sites. The scope of this report is to provide a preliminary evaluation of growth and variation in fundamental wood properties from known-age planted Natapoa trees, and to assess if there are variations in wood properties across age, sites and provenance. The results of the study have been used to produce extension materials, inform the development of a scientific conference presentation and will form part of the data in a scientific paper. The results will help to provide data to inform silvicultural management, utilisation and economic modelling for this emerging species.

4 Objectives

The objective of this research is to assess growth and wood quality from three stands of planted *Terminalia catappa* (Natapoa) in Vanuatu. The data collected on growth and wood properties will be used to develop information for landowners interested in planting high value timber trees. The scope of this study is to provide a preliminary assessment of growth and variation in fundamental wood properties from known-age planted Natapoa trees, and to assess if there are variations in wood properties across age, sites and provenance. The study assessed the growth performance and made a preliminary evaluation of heartwood formation across a range of sites and provenances (basic density and heartwood/ sapwood ratio). The following activities were undertaken to compile important data and to develop information for landowners interested in planting native timber trees:

- *Literature review to determine the current state of information on the growth and wood properties from Terminalia catappa;*
- *Site visits - Growth assessment and wood sample collection across three sites in Vanuatu;*
- *Sample processing- to determine wood density and wood properties from planted Terminalia ;*
- *Data analysis;*
- *Preparation of Extension Materials.*

5 Methodology

Project activities will include preparing a literature review and a field based data collection program across three sites in Vanuatu. The project activities will include

1. *Literature review*
2. *Site visits and stratification of plots*
3. *Growth assessment*
4. *Wood core collection*
5. *Sample processing*
6. *Data analysis*
7. *Preparation of Extension Sheet for Landowners*
8. *Reporting*

The major output of this Small Research Activity (SRA) project is a report on the growth and preliminary wood properties of *Terminalia catappa* planted in mixtures and pure stands from aged 4 to12 years old, in Vanuatu. The growth from approximately 400 trees was collected from this initial assessment the selection of sample trees for wood core collection was made from three agroforestry plots. The collection of 60 wood cores was conducted to determine basic density of the species across sites and age classes. An assessment of heartwood formation across provenances was conducted within a key site.

Heartwood formation and wood colour is a parameter that is useful to determine harvest age and wood value in decorative timbers (Bootle 2005). The study will identify the age and extent of density, wood colour and heartwood formation across a range of sites and provenances. The results of the study will be used to produce extension materials and to provide preliminary data to inform silvicultural management, utilisation and economic modelling.

5.1 Activity 1- Literature review

Terminalia catappa has been identified as a significant species for agroforestry, however the scientific literature to support the development of this species is not well developed. A literature review has been prepared that focuses on the existing information on the ecology, silviculture, uses (timber, nuts, medicinal), agroforestry potential and socio-economic values of this important tropical multi-purpose tree species. The aim of the review is to evaluate the value of this species in mixed species agroforestry systems. This review will provide the introduction to the report and to any potential scientific paper, extension material and PowerPoint presentations. Results from early growth in mixed stands containing Natapoa was the focus of the presentation by Leimon Kalomor on mixed species plantations at the ACIAR Whitewood Workshop in Luganville, 2012.

5.2 Activity 2- Site visits and stratification of plots

Site visits and planning for data collection for five planted Natapoa stands was conducted from November 2011 to March 2012. The initial site for the collection of early growth was the Malakai mixed species trial at Sara and the Jubilee Farm demonstration planting. The sites were visited in the months from February to April 2012, where both wood samples and growth were collected, some preliminary to measurement and wood sample collection was undertaken at this time. Sites were stratified on the basis of age and tree spacing. Wood quality data was collected across 3 sites- Industrial Forestry Plantations (IFP) at Shark Bay (Santo), “Wood Farm” at Fanafo and “Tranut” Teouma- Efate (See Figure 1 and 2), the selection and data collection activities were conducted by VDoF (Joseph Tongun, Taura Titus, Mesek Sethy, Leimon Kalomor, David, Mackenzie and Olister) and SCU Project staff.

Site 1- Industrial Forestry Plantations (IFP). The IFP trial represents the oldest Natapoa plantation site in Vanuatu. This site on the east Coast of Santo, the largest island in the nation comprises a collection of families from around Vanuatu. The original spacing was (6mx4m) with trees having been culled prior to measurement. The diameters of a subsample of trees were measured in November in 2011 and an additional measurement was undertaken again in May 2012. The diameter at breast height (DBH-1.3m) was recorded for 61 trees in 2011. In 2012, the DBH and stem form were measured on 67 trees and 20 wood cores were collected from this site. The wood cores were collected using a 6mm hand Hagloff corer. In November 2012, six trees were harvested from the IFP Natapoa trial to collect more comprehensive wood samples for wood properties analysis.

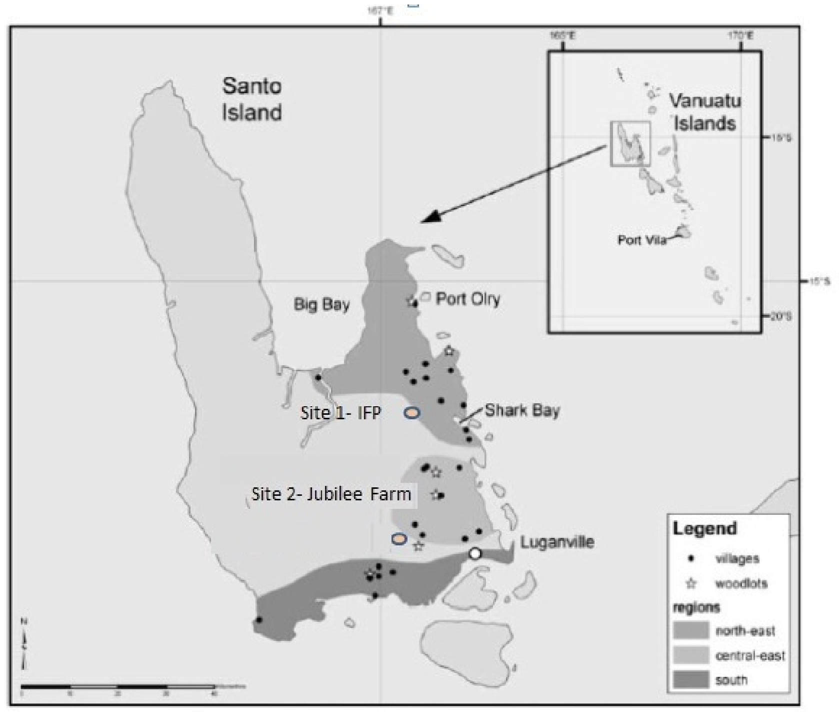

Figure 1 Map of Espiritu Santo, Vanuatu. (modified from Grant *et al* 2012)

Figure 2 Wood coring in 12 year old trees at IFP (left) and the IFP natapoa stand at Shark Bay, Santo.

Site 2- Jubilee Farm- Bradley Wood Plantation. The Bradley Wood plantation was established over 2 years with the first planting in 2002 and a subsequent planting in 2004. The tree growth and wood cores were collected in May 2012. In the 8 year old planting 80 trees were measured (spacing 4x3m) for DBH and stem form, and 12 wood cores were collected across diameter classes. In the 10 year old planting (spacing 5x3m), DBH was measured on 40 trees and 12 wood cores were collected (See figure 2 below).

Figure 3 Wood core samples collected using a small wood corer by Leimon Kalomor on a 10 year old tree at Jubilee Farm (left) and the 8 year old planting at Jubilee Farm (Right).

Site 3 Tranut Plantation Teouma. This Natapoa planting located approximately 10km from Port Vila (Figure 3), was established in 2002 at a spacing of 5m x5m. The stand had been lightly thinned to approximately 350 stems per hectare in 2010. The diameter of 60 trees was measured and 12 wood cores were collected across diameter classes.

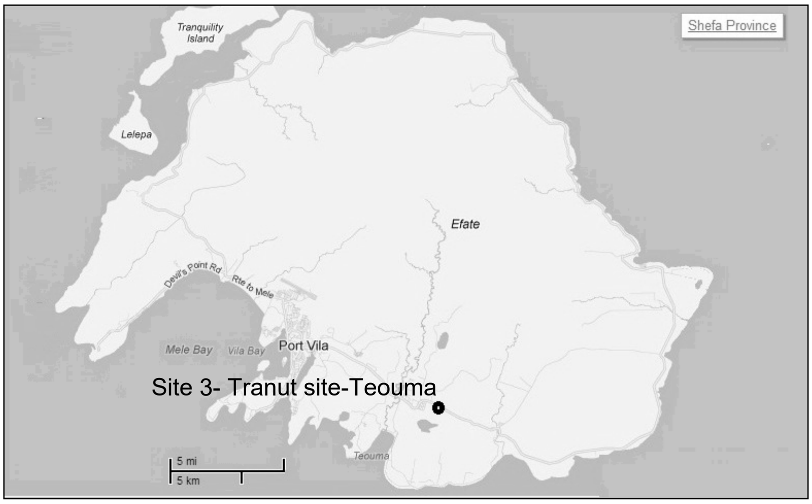

Figure 4 Location map for Tranut site at Teouma, Efate.

Site 4 Jubilee Farm- James Edwin. James Site 4 is a mixed species planting established in 2008 in an area that was used as a garden with annual crops (corn, vegetables), taro, kava, banana and papaya. The tree rows were located every 8 metres with the trees spaced at 3 metres within the rows (see figure 13). The mixture included Natapoa planted with whitewood (*Endospermum medullosum*) and namamau (*Flueggea flexuosa*) in this system Natapoa is planted at approximately 110 trees per hectare. The mixed species planting of 0.5 ha at the site has been established and managed as a demonstration site, to show farmers a mixed species agroforestry system. Natapoa has also been planted at Jubilee Farm- Edwin's, amongst coconuts using the same mixed species design as in the garden mixed planting (James).

Site 5 Malakai Mixed trial- Natapoa has been planted in a 2 hectare mixed species trial at Sara in north eastern Santo in 2009. The Natapoa is planted in a mixture with whitewood and namamau in an area that was covered with "big lef" *Merremia peltata* vine and degraded secondary forest. The spacing in the mixture is 8 m between rows and 2m between trees, with the Natapoa established at 150 stems per hectare

5.3 Growth Assessment

The diameter growth of Natapoa across a range of sites and age classes was carried out to determine the rate of diameter growth. Direct measurements of height were and stem taper were undertaken at IFP to help estimate the volume and growth increment on the oldest site. Tree heights of Natapoa in the young stands were measured; however, the impact of stem borers on the growing tips has had an impact on apical development in many trees.

Stem diameter: Diameter at Breast Height (DBHOB-1.3m) was measured with a tape or callipers, and diameters at 1 metre intervals were taken on any felled trees. The collection of this data will allow the generation of accurate taper models and accurate stem volume calculations. Stem diameter at 1.3m (DBHOB) at a given age was used to calculate an annual diameter increment. The annual diameter increment and height allowed for calculation of stem volume. The annual volume increment can be used as an index of site quality, thus allowing some comparison between sites in terms of productivity.

Stem height: Tree heights were measured on the trees from the younger sites, (Site 4 and 5) using a height pole and a vertex on the taller trees (160 heights across the sites). In the IFP site tree height was measured directly on felled trees using a tape (stem taper and height measured on 6 sample trees).

Stem Form: The assessment of the form of the trees will provide some qualitative analysis of the stem regarding straightness, obvious insect or mechanical damage, degree of branching, and forest health issues. The ability to produce a straight, defect free stem (bole) will determine the economic returns from timber to growers. The form score is

Trees were classified into one of three groups:

1. *Crop trees*: were the straightest, free of defects and suitable for pruning;
2. *Minor defect trees*: minor stem deviations, minor deformities on trunk, largest branch <50 mm diameter, lean <5% but were deemed as merchantable. These could be pruned but would result in lower quality products (the cost of pruning is less likely to be recouped).
3. *Cull trees*: had a major defect in the lower section of the stem (ramicorns, double leaders, very large branches >50 mm, severe stem deviations, broken tops) and were considered unmerchantable.

The questions of interest were;

- What are the total number and spatial variation of crop or merchantable trees available for pruning at each site?
- What is the proportion of trees in each stem class?

The optimum number of trees for final harvest in a solid wood regime on high quality sites to ensure full utilisation of the site while maintaining growth rates and is generally considered to be about 200–400 trees per hectare (West 2006). Therefore 200 trees per hectare was used as an indication of adequate stocking. A total of 732 trees were assessed in two stockings and three spacings (IFP- 5 x Wood- Jubilee Farm: 4 × 3, 5 x 3m, Trunut: 6 × 4, 8 × 3).

5.4 Wood quality assessment

The wood core samples were collected from trees at Breast height (130 cm) on the north side of the tree where possible (Figure 5). However, Raymond and Munari (2001) pointed out core orientation does not appear to be significant but they suggest sampling on the same orientation on a given site. If there is a significant bend in the stem an additional core perpendicular to the lean of the tree will be taken to reduce the chance of sampling reaction wood. The wood properties that will be determined are density (Green, air dried and basic) and heartwood/ sapwood ratios where possible.

The trees selected for sampling will be within the 95 percentile group in terms of diameter growth for that species, at that site and age class. The sampling will avoid edge trees and extremely bent trees to reduce the chance of sampling individuals with higher degrees of reaction wood. The sample trees will be selected to represent the relative size diameter classes present at each site. Therefore, the proportion of stems in a given size class selected for sampling will reflect the population of that species at that site. Across all sites 54 wood cores were collected and the basic density determination made.

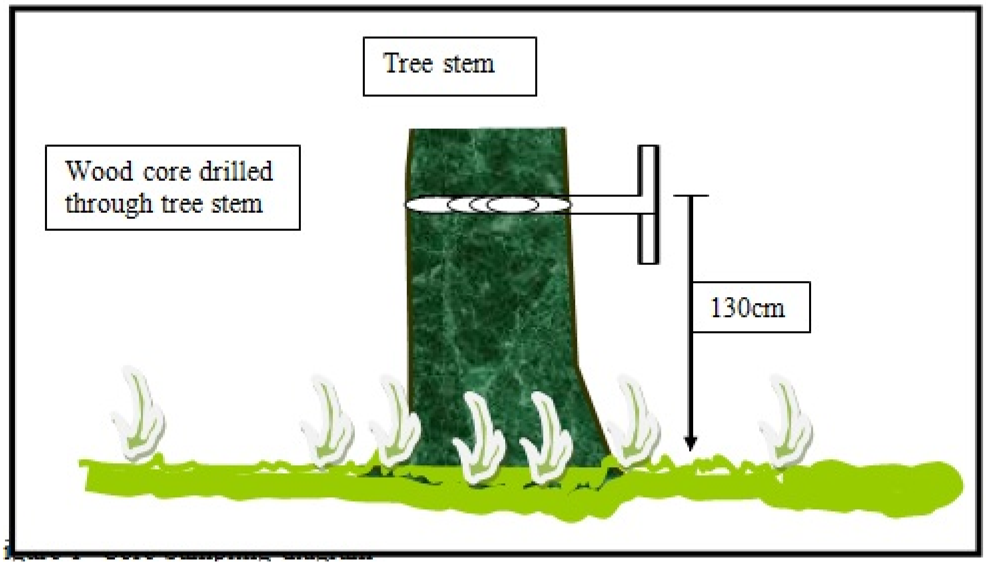

Figure 5 Wood cores collected from sample trees at 1.3 m above the ground in a north south orientation, where possible.

All wood cores were placed into a sealed zip lock bag and a small amount of bleach was sprayed onto the sample to reduce the risk of mould or fungal damage to the wood sample, and core placed in a sealed plastic bag (Figure 6). The samples were refrigerated to keep the samples cool and moist.

Figure 6 Wood core in sample bag with label.

Wood cores were collected from 3 sites, with 44 cores collected in April 2012 and 12 cores collected in August, 2012. The wood cores were taken from trees that were representative of the range of size classes at each site. Cores were collected from 12 trees in both 8 and 10 year old plantings at the Wood Farm at Fanafo, a further 20 wood cores were collected from IFP from the 12 year old trees. In August 2012, 12 wood cores were collected from the 10 year old trees at the Tranut site on Efate. The wood cores were collected with VDoF staff from all sites, where the technical aspect of collecting the wood samples was imparted to the in-country staff. The wood cores were collected in such a way that the corer was sterilized between use on trees, all the core holes left in trees was disinfected with bleach and the holes plugged with hardwood dowels to reduce the risks of post sampling infections.

5.4.1 Estimation of wood density using wood cores

Determination of basic density

Basic density is expressed as the ratio of the weight of the oven dry sample to its green volume. The units used for the quantities are usually (kg) for the dry mass, and (m^3) for the wood volume. Measurement of wood density using the water-immersion method is the most direct method (Figure 7). A further method for determining basic density uses the maximum saturation method. Both methods require a specific specimen to be measured. The water-displacement method requires the evaluation of weights and volumes whereas the maximum moisture method only requires the evaluation of specimen weights, but the green sample must be initially fully water saturated.

Equipment

• An electronic balance (accurate to at least 0.1g) is preferable for weighing the sections.

• A container holding enough water to fully submerge the sample.

• A fine needle point to hold the submerged wood samples at a minimal fixed depth.

• A well-ventilated oven with automatic temperature control is needed for drying the sections.

The oven requires shelves of wire mesh or other open material to allow free internal circulation of air. Otherwise, the sections may not dry thoroughly. The temperature at any point inside the oven should neither exceed 105°C nor fall below 101°C; this degree of uniformity is generally achieved by using a double-shell construction or by the use of a circulating fan inside the oven. Below 100°C the sections may not be dried completely, and above 105°C they may char.

Procedure for water displacement determinations

1. In the laboratory, place the sample into water for at least a day to ensure adequate swelling/ saturation.

2. Place the water container on the pan of the electronic scales and re-zero (stand and needle not included). Electronic Scales (accurate to 0.01gm)

3. Remove the sample from the water, wipe with a damp cloth, and then completely submerge in the container on the electronic scales, without touching the container, (as shown- using a sharp needle probe mounted on a stand with the wood core wood sample secured to the end of the needle). Stand with needlepoint probe to keep core sample submerged just below the water surface. Core samples were immersed in water in 100ml flask.

4. Record the increase in mass on the scales of the sample is fully submerged. As the density of water under normal laboratory conditions is equal to 1000 kg/m^3, the measured weight of the displaced water is equal to the volume of the sample.

Basic density is calculated by the formula:

$$\textbf{Basic Density} = {}^{\mathbf{m_o}}/\,\mathbf{V}$$

where m_o=oven dry weight;

V=volume of fully saturated sample. (Units kg/m^3.)

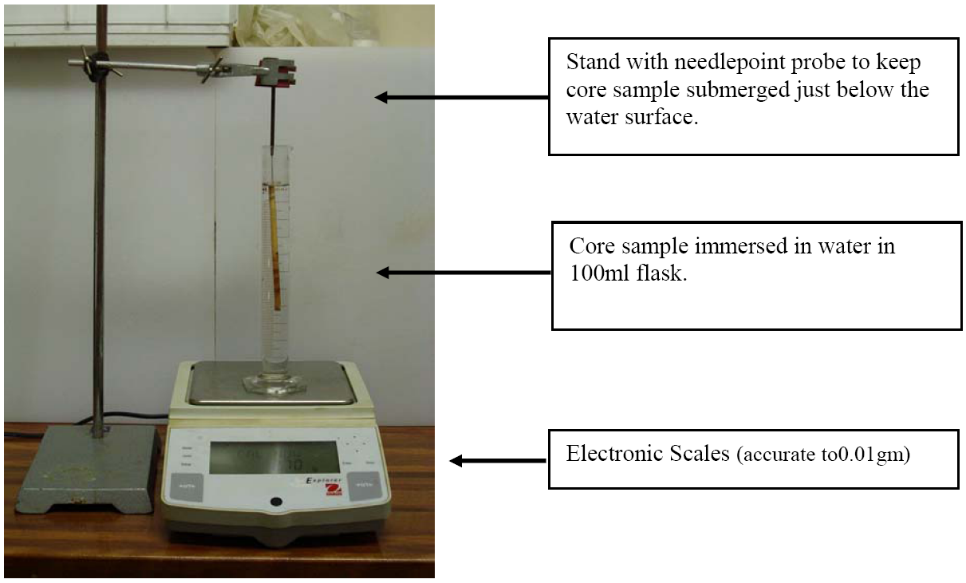

Figure 7 Apparatus required to measure the green volume of wood cores

5.4.2 Collection of larger wood samples from IFP

Harvesting of sample trees and collection of large wood samples for more detailed analysis was undertaken in November of 2012, at the IFP trial at Shark Bay. Six trees were cut down to collect a disc and billet from Breast Height to determine wood density from discs and larger wood samples, these billets were used to produce wood samples for further testing (see Figure 8). The sample trees also provided samples for assessment of heartwood formation and a qualitative assessment of wood colour.

Figure 8 Logs cut to produce larger wood samples from 12 year old Natapoa trees at IFP.

Harvested trees were sawn to yield a disc 30mm thick from breast height (1.3m), another disc was cut at 6.0m along the log and a third disc was cut at below crown break. The discs were then cut to produce 2 wedges one wedge was kept whole and the second was cut to provide a sample for inner wood and outer wood (Figure 9).

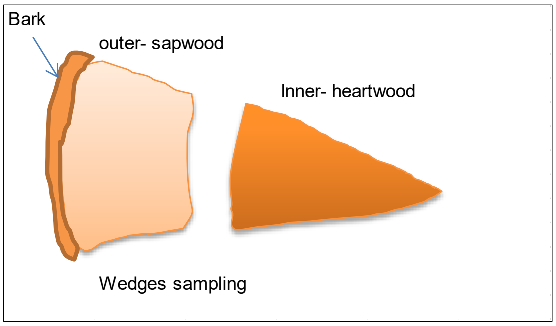

Figure 9 Wedges cut from the harvested trees at IFP (Site 1) for analysis of wood density from heartwood (inner) and sapwood (outer).

A billet was cut above the breast height disc 1.2m long this log was then taken to be milled into samples for further analysis. The billets were then sawn to produce a 60mm slab that was re-sawn to produce 50mmx50mm sections 750 mm long for wood properties assessment. From these samples were cut to measure wood density and shrinkage.

6 Achievements against activities and outputs/milestones

- *Literature review*
- *Site visits and stratification of plots*
- *Growth assessment*
- *Wood core collection*
- *Sample processing*
- *Data analysis*
- *Preparation of Extension Sheet for Landowners*
- *Reporting*

6.1 Literature review- February to April, 2012

The collection of information on Natapoa was initiated by Leimon Kalomor in November, 2011. A work plan was developed that involved some database searches and a sampling strategy by Leimon. Early discussions with key Vanuatu Department of Forests staff included a meeting with Joseph Tongun on the 23rd of April in 2012, where Joseph made some important observation on Natapoa. Mr Tongon observed:

- Best heartwood development on sandy or stoney sites, where it grows more slowly. Best growth on well drained slopes;
- very good at recovering after cyclones or major tip damage;
- regenerates very well on lowland rainforest remnants;
- Selection at IFP based on kernel production rather than timber production.

The project scientists and technical staff have also approached wood processors in Vanuatu to determine the current market demand, pricing and utilisation of timber from *Terminalia catappa*. Whilst this information may not form the part of the literature review, it helps to determine that there is an interest and demand for the wood processing from Natapoa.

6.2 Site visits and stratification of plots- February to April 2012

Growth data was collected across 5 sites, rather than the 3 sites scheduled under the original outputs and milestones. The five selected sites represent a broad range of planting types, including single species farm forestry plantings, mixed species systems, research trials and plantings in degraded secondary forests. The plantings ranged in age from 3 years old to over 12 years. The older sites have generally been thinned however; the 8 and 10 year old plantings at Fanafo, owned by Bradley Wood are shelterbelt type plantings that are in need of thinning

The two additional sites included in the data collection provided the opportunity to compare early growth in mixtures with the older sites monoculture plantings. The wood quality data was collected across 3 older sites- Industrial Forestry Plantations (IFP) at Shark Bay (Santo), Teouma- Efate and Wood Farm at Jubilee Farm, in line with the milestones plan. The selection and data collection activities were conducted by VDoF and SCU Project staff. A Work Plan was developed in April 2012 by VDoF and SCU Staff to inform the data collection process.

6.3 Growth assessment- February to November 2012

The growth of Natapoa was assessed across several age classes. Whilst the growth at many sites has been encouraging, there are some signs of damage in young trees from an unidentified shoot boring caterpillar and defoliators. The impact of the insect damage on Natapoa will need to be monitored to ensure that wood quality and productivity are not compromised on certain sites. Height data was collected in February and November.

The assessment of the growth (DBH) was carried out for over 400 trees across 5 sites that represent a range of ages and forestry systems (mixed species and Monoculture). The growth assessment was carried out as planned and the outputs and milestones were met. In early 2012 the height and diameter of 94 trees was conducted for the mixed species trial at Sara. At the IFP site there were 129 tree diameters measured. At the Wood site at Jubilee Farm- Fanafo, the growth and form of 120 trees were measured. On Efate, the diameter growth of 64 trees was carried out.

The questions of interest on the older sites were; the total number and spatial variation of crop or merchantable trees available for pruning at each site, and the proportion of trees in each stem classes. The optimum number of trees for final harvest in a solid wood regime on high quality sites to ensure full utilisation of the site while maintaining growth rates and is generally considered to be about 200–400 trees per hectare (West 2006). Therefore 200 trees per hectare was used as an indication of adequate stocking. A total of 407 trees were assessed in monoculture plantings at three stockings and four spacings (IFP- 5 x 10m, Wood- Jubilee Farm: 4 × 3m and 5 x 3m, Trunut: 10 x 5m). Natapoa diameter and height were growth were also measured in the mixed species plantings, with Natapoa trees at 2 stocking levels Sara 8x12m, Jubilee Farm and 8x8m..

6.4 Wood core collection- March to April 2012

By April 2012, the project team had identified 62 trees from three sites for collection of wood cores; 56 wood cores and an additional 6 trees harvested for 32 wood samples from discs (to produces wedges) and billets. In addition to the wedges the wood density was also determined using 22 larger samples cut from the breast height billet 700mm long the original plan it was anticipated to collect 60 wood core samples only, the project collected and determined the wood density on 108 wood samples in total. The aim to determine the basic density, heartwood sapwood ratio, wood colour and variation within sites and across sites and ages, was achieved and additional analysis was conducted on harvested trees in November 2012.

The collection of larger wood samples, beyond wood cores, was carried out in late 2012. Harvesting trees has some important benefits in terms of understanding the wood properties of Natapoa. The collection of larger wood samples allows the comparison of wood cores with more precise measurements of wood density from wood discs and billets at various heights along the stem of sample trees at a key Natapoa site at Shark Bay. The collection of logs allows for measurement of wood stability and drying characteristics.

6.5 Sample processing - April 2012

Wood samples were processed and dried under controlled conditions at SCU Wood Science Laboratory, in accordance with the relevant standards. The data from field sites was analysed by the VDoF Project officer, Vanuatu Agriculture College staff and SCU Project Scientists. The wood cores were collected and processed in two rounds: 44 wood cores collected in April 2012 in and an additional 12 in August 2012. The larger wood samples were collected in November, 2012 where an additional 52 samples were processed.

6.5.1 Wood cores

The wood cores were divided into 3 sections prior to analysis of the wood. This allows the wood in different sections of the stem to be looked at in detail. The 6mm samples were separated into heartwood (inner), sapwood (outer) and both (inner and outer). This resulted in the 20 wood cores collected from IFP producing 63 individual wood samples. The 12 wood cores collected from the 8 year old trees from Bradley wood Farm producing 33 wood samples for processing. The 10 year old trees from the Wood Farm produced 35 wood samples. So in total, the collection of 56 wood cores resulted in 131 wood samples that were weighed, oven dried to determine the green density and basic density.

6.5.2 Larger wood sample processed from harvested trees at IFP.

The collection of discs and larger wood samples from the 6 trees harvested at IFP resulted in the processing of 18 discs from three locations up the stem in each tree, 1.3m, 6.0m and crown break (variable distance) (Table 6 and Figure 16). The wedges were cut with a bandsaw to separate the heartwood and sapwood, where the boundary could be determined. This resulted in the 18 discs producing 33 wood samples for determination of green density, air dry density and basic density.

The processing of the larger wood samples from billets collected from IFP was undertaken in Vanuatu with the involvement of VDoF staff. The billet was sawn to produce a 60mm slab from the centre of the log using a chainsaw mill (see Figure 17). The sawing and processing of the six logs from IFP produced 22 wood samples where the green density, air dry density and basic density were calculated.

6.6 Data analysis April 2012

The data analysis of growth was conducted in April 2012. The wood samples were analysed over 3 periods from April 2012 to November 2012, as data became available. The reporting and publication of this data in scientific literature is still under development.

6.7 Preparation of Extension Sheet for Landowners

The preparation of extension material began in late 2011, with the development of a mixed species powerpoint presentation that focussed the early growth of Natapoa, delivered by Leimon Kalomor. A follow up presentation was given at the Whitewood inception meeting in Port Vila and Luganville that included reference to growth of Natapoa in Efate and Santo. In February 2013, a site visit to the Tranut Natapoa planting was undertaken with VDoF personnel and researchers from SCU and University of New England. A poster on the silviculture and wood properties of Natapoa has been prepared in Bislama. A paper for presentation at an international conference in 2013 is currently under development.

7 Literature review.

Terminalia catappa L., Beach Almond, Tropical-Almond, false kamani,

7.1 Distribution and environmental requirements

Terminalia catappa (T. catappa L. (Combretaceae)) is native to near-coastal areas of the Indian Ocean, tropical Asia and throughout the south Pacific and has been spread by humans throughout the tropics (Thomson and Evans 2006). Tropical almond occurs entirely in frost-free subtropical and tropical zones, usually near to the coast (Figure 10). It prefers light, sandy soils and can tolerate brackish or saline and alkaline soils over limestone. It appears to be highly tolerant of strong winds and of salt spray.

Figure 10 Natapoa Planting on a flood plain near Port Vila, in Vanuatu.

7.2 Knowledge base

A search of the electronic database “Web of Science” under “*Terminalia catappa*” yielded 163 references published between 1978 and 2012. None of these included the term “silviculture” as a key word. Most had to do with chemical properties of the species, or with nut production. Not included was the very useful and thorough overview of the species and its uses by Thomson and Evans (2006).

Natapoa, *T. catappa,* is known mainly as a coastal fringe tree, planted for amenity purposes near human settlements. Little is reported in the literature about its behaviour in plantations, if indeed it has been planted in pure stands. Other than Thomson and Evans' species profile, there is little published on its recommended silviculture and potential productivity.

7.3 Wood properties

Natapoa can be used for general building construction, flooring and furniture, and large well-shaped logs can be used to produce veneer.

The heartwood varies in color from brown to reddish-brown, accompanied by a lighter colored sapwood.

Thomson and Evans (2006) reported a **density** of 530-540 kg/m3 at a moisture content of 12%, whereas Butaud et al. (2008) suggest a mean density of 053 with a range from 0.46 to 0.58 and Little and Skolmen (1989) reported a specific gravity of 0.59.

Durability is rated as low, with wood being unsuitable for long-term ground contact. Chudnoff (1984) reported that heartwood is very susceptible to dry-wood termite attack.

Wood is reported to season rapidly with moderate amounts of warping and little checking.

Natapoa saws and machines easily but is can be torn so that fuzzy grain results from the planning, shaping, and turning processes.

7.4 Nuts

Nuts can be consumed directly after harvest or preserved by drying or smoking. Fresh kernels are sometimes sold in bundles skewered in palm fronds in markets and are considered to be an important food in Vanuatu (Thomson and Evans 2006). They sell in markets for approximately $12-17 per kilo, whereas pure dried kernels are retailed in supermarkets for around $80 per kg.

Trees grown exclusively for nuts should be planted at wide spacing, 8 to 9 meters apart, with ample exposure to sunlight, and with the lead shoot pinched out to encourage lateral spreading. The low, heavily branched structure of a fruit or nut tree is fundamentally different from that of a tree grown for timber, in which the objective usually is a single straight stem. But Thomson and Evans (2006) suggest a plantation can be established that produces both nuts and timber, with an initial stocking of 625 trees per ha with a spacing of two m within rows and eight m between rows and following a program of non-commercial thinning so that a final stocking of 150 trees per ha is achieved by age six.

7.5 Other uses of *T. catappa*

In traditional medicine

Many more articles in the scientific literature focus on chemical properties of (Chitmanat et al., 2005; Phulwaria, et al. 2012) of T. catappa than on its uses as a timber or nut-producing tree

For example, Baratelli et al. (2012) investigated allelopathic properties of the species and concluded that there appears to be a complex of compounds that interact with each other to produce an allelopathic effect.

8 Key Results and Discussion

8.1 Growth Assessment

8.1.1 Growth Assessment of Natapoa in Mixed Species Trials at Sara

The youngest trees in the assessment are plantings in demonstration sites and trials set up under the ACIAR Whitewood project. The plantings have been measured annually since planting, to determine the growth of promising species in mixtures. The Natapoa has survived well with over 95% survival at 2 years old in a mixed species trial at Sara (Site 5 see Figure 11).

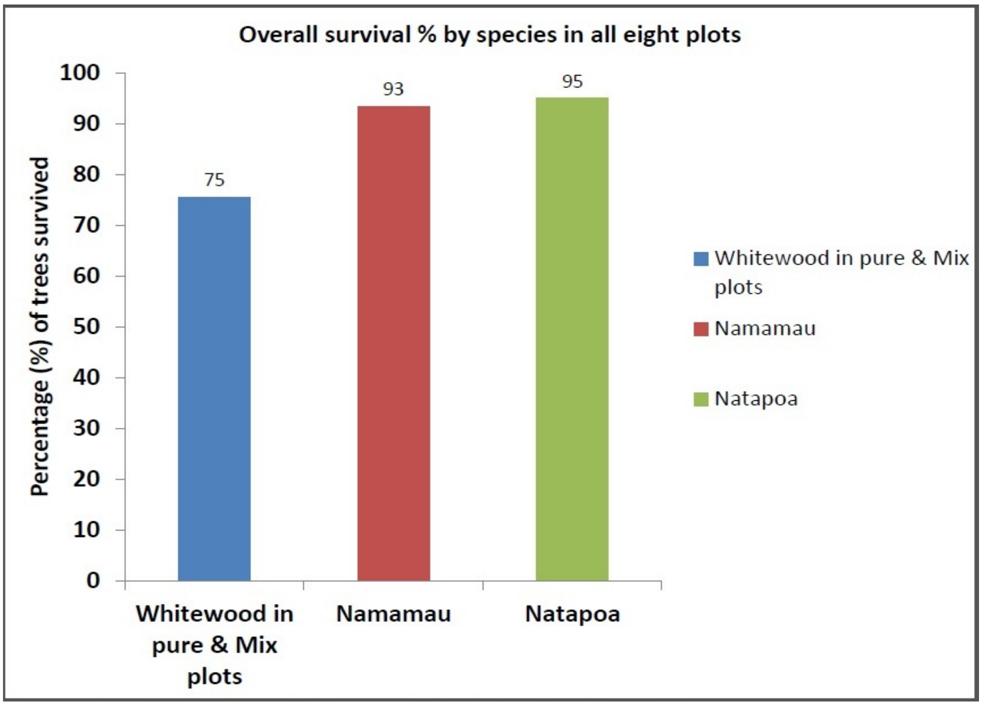

Figure 11 Survival of Natapoa in mixed species plantations on Santo, (from Kalomor 2011).

The early growth of trees in the mixed species trials at Sara has shown signs of suppression under remnant trees in some plots. However, the growth in diameter has been encouraging at 5cm in diameter in 2 years, slower than whitewood (*Endospermum*) and approximately the same as namamau (*Flueggea*). The height growth of Natapoa at two years of age is lower that Whitewood and Namamau, at 3.8m (Figure 12). The height growth was adversely affected by the damage caused by shoot boring caterpillars.

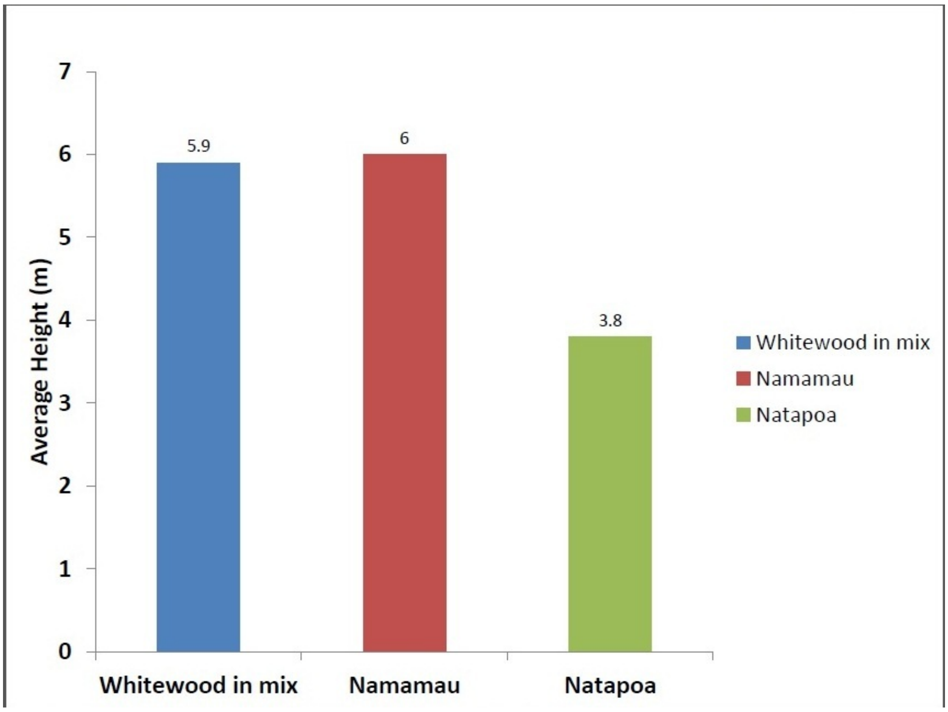

Figure 12 Height (m) of Natapoa in a mixed species trials, at Sara Santo at 2 years of age (Site 5- source Kalomor 2011).

At a mixed species trial at Sara, Natapoa has shown signs of insect damage and competition from surrounding trees. The DBH is only 30mm at 2 years old, which is much lower than the other species in the trial (Table 1 and), the height of Natapoa was lower due to high percentage of stems that showed damage from shoot boring caterpillars (Figure 13).

Table 1 Growth of Natapoa at a mixed species trial at Jubilee Farm at 3 years old Natapoa (NTP), Namamou (NMM) and whitewood (WWD).

	mixed species			Monoculture
	NTP*	NMM*	WWD*	WWD
spacing	8x8m	8x4m	8x8m	8x3m
Stocking (actual)	122	305	132	300
total basal area (m^2/ha)	0.09	0.89	1.70	4.35
Dbh mean (mm)	31	61	128	138
Ht (m)		4.8	8.3	9.7
mortality %	21	7	27	24
form	2.6	1.9	1.91	1.79
n	61	118	44	91

Figure 13 Young Natapoa showing signs of insect damage, with damage to growing tips affecting the stem form (left) and significant branch damage (right).

The impact of the borer damage on stem straightness (Stem Form) can clearly be seen in results from the mixed species trials at Sara after 3 years (Figure 14). Over 90% of the trees assessed had a fair or poor stem form, which is of concern for the future wood quality from this planting at this early stage.

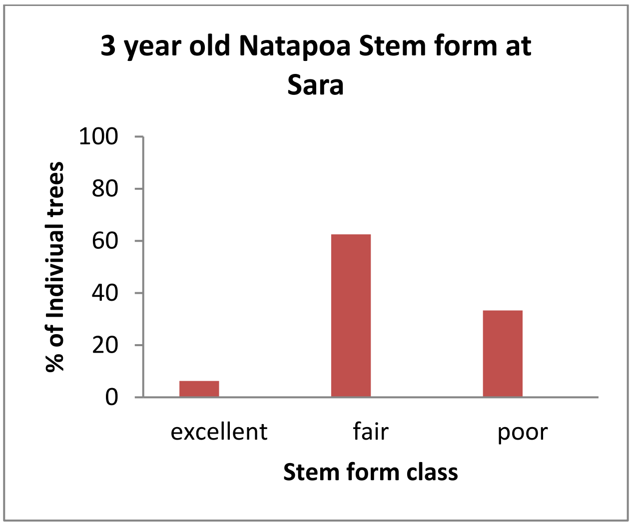

Figure 14 Stem form of Natapoa at Sara mixed species trial at 3 years of age

8.1.2 Growth Assessment- Jubilee Farm- James Edwin's

The demonstration site (Site 4) at Jubilee Farm- Edwin's, is a mixed species planting established in early 2009 in areas that were actively gardened. The growth of Natapoa was encouraging on trees that were free of borer damage (Table 2, Figure 15). Natapoa was over 10.5cm (105mm) at 3 years and had the lowest mortality of the 3 species at 17%.

Table 2 Natapoa at Jubilee Farm- James Edwin's at 3 yrs old

plot	spp	planted	n alive	mortality %	dbh (mm)	stdev
mix	natapoa	65	54	17	105	35
mix	namamou	144	102	29	70	15
mix	whitewood	78	57	27	175	29

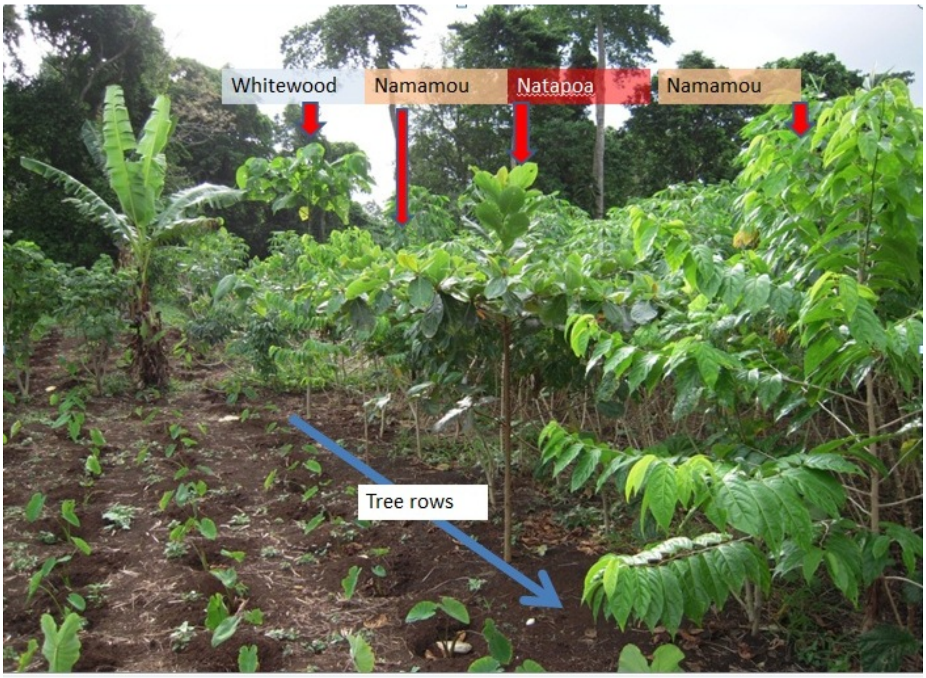

Figure 15 Mixed species agroforestry planting at Jubilee Farm with natapoa, whitewood and namamou at 2 years old.

8.1.3 Growth Assessment – Bradley Wood Farm at Fanafo

The diameter growth of the Natapoa in the older stands is much more encouraging, the planting established by Bradley Wood at Jubilee Farm (site 2), has grown at 22mm in diameter per year to year 10 and 26mm per year to year 8 (Table 3). The data is indicating signs of slowing growth due to competition, and the trees would benefit from thinning to reduce competition and to focus the growth across the site on the most valuable trees.

Table 3 Growth of Natapoa at Bradley Wood Farm, Fanafo.

site	n	spacing	DBH (mm)	stdev	MADI (mm)
wood-8yrs	68	4x3m	205	49.6	26
Wood-10yrs	38	5x3m	225	66.5	22

MADI- Mean Annual Diameter Increment in mm

8.1.4 Growth Assessment at IFP, Shark Bay

At IFP (Site 1) the Natapoa trees are growing well, with a mean diameter of 294mm at 12 years of age, with an annual diameter growth of 24mm per year. The stand is currently thinned to approximately 210 stems per hectare (Table 4). The largest tree is 481mm in diameter,

Table 4 Growth of Natapoa at IFP at 12 years old.

Site	Age (yrs)	n	spacing	DBH (mm)	Max (mm)	MADI (mm)
IFP	12	129	5mx 10m	294	481	24.5

MADI- Mean Annual Diameter Increment in mm

The stem form at IFP is much better than the younger sites, with 6% of stems showing poor form, 35% were excellent straight trees. At a stoking of 210 trees per hectare this represents approximately 75 excellent crop trees per hectare (Figure 16).

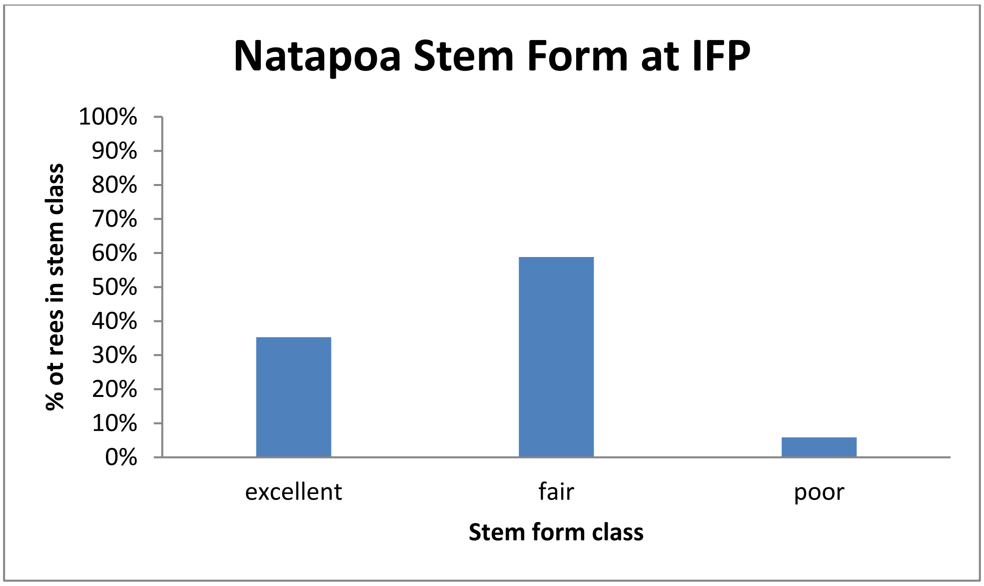

Figure 16 Stem form at IFP at 12 years old.

8.1.5 Growth Assessment- Tranut, Teouma Efate.

The Natapoa tree growth rate at Tranut site Teouma (Site 3) was highest across all the sites at 27.5mm per year at 10 years old (Table 5). The stand is heavily stocked, as there are 350 stems per hectare on the site at the moment. The mean diameter is 275 mm and the largest tree was 427mm in diameter.

Table 5 Tree growth at the Tranut site at Teouma, Efate at 10 years old.

Site	Age (yrs)	n	spacing	DBH (mm)	Max (mm)	MADI (mm)
Tranut	10	63	5mx 6m	275	427	27.5

Stem form at Tranut site was not as good as the IFP, but the stem form and growth could be improved by removing the smaller and poorest form trees. Poor form trees represent 45% of the stand, only 5% of the measure trees were excellent straight trees (Figure 17).

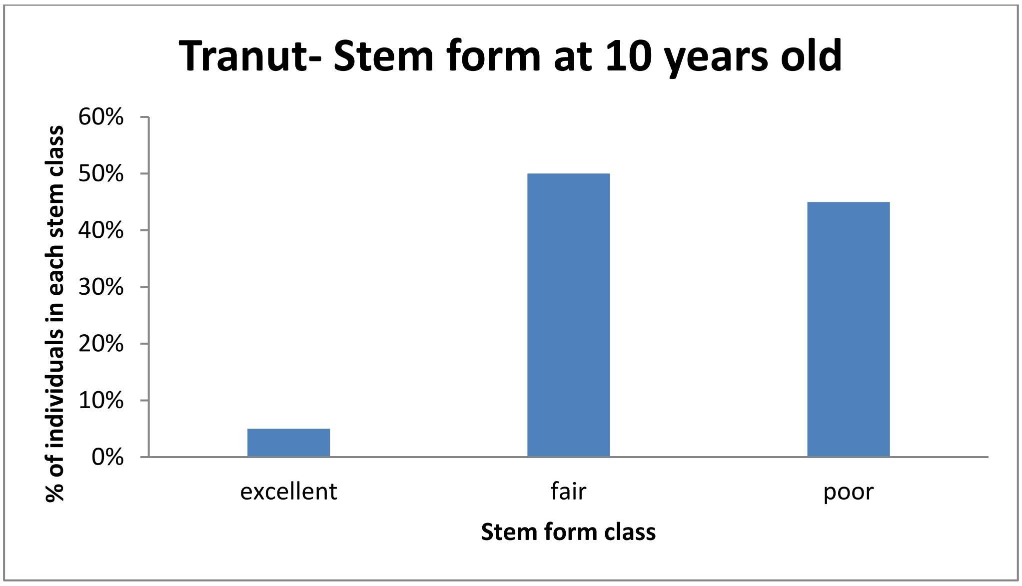

Figure 17 Tree form at Tranut site at 10 years old.

8.2 Wood Core Collection- Wood density across the stem and heartwood formation

The determination of basic density was made at 3 locations for each of the wood core samples, for the inner wood (heartwood), the outer wood (sapwood) and both inner and outer wood (heartwood and sapwood). The location of the boundary between these zones was difficult to determine in a number of samples using the standard methods of chemical indicator (Methyl Orange). In the younger trees very often the formation of heartwood was not apparent, and therefore the wood can be considered all sapwood. Usually heartwood can be determined through obvious changes in wood colour across the sample or a chemical indicator will clearly determine the sapwood /heartwood boundary. In the wood core samples, the use of methanol to clean and disinfect the samples prior to arrival in Quarantine in Australia may have reduced the efficacy of the indicator to determine the sapwood boundary.   To more clearly and accurately determine the heartwood formation in Natapoa a collection of the discs was undertaken. The wood properties data has been analysed for each of the wood sample types, so density is given for wood cores, wedges and the larger wood samples.

The density of the wood cores is given as green and basic density to ensure that the wood data is comparable across sites and comparable with published technical data. Where the boundary of heartwood was difficult to determine the sample was divided into inner and outer wood and the wood density determined (Table 6). The trends in wood density across the samples were variable, with the outer wood being of slightly higher density in 3 of the four sites. The inner wood of the oldest trees at IFP (Site 1) was denser than the outer wood. The densest wood samples collected were the outer wood from ten year old trees at the Tranut site (Site 3) at 552 k/gm^3. The result from this study of density from wood cores indicates that the wood from these young trees is similar to that of mature wood from the published literature (Thompson and Evans 2006).

Table 6 Basic Density and Green Density from wood cores collected at 3 sites in Vanuatu

site	yrs	Basic Density (Kg/m3)				Green density (Kg/m3)			
	age	inner	outer	both	n	inner	outer	both	n
IFP	12	500	477	488	60	859	853	857	60
Wood 8yrs	8	406	433	397	36	876	874	893	36
Wood 10yrs	10	397	416	409	36	887	876	891	36
Tranut	10	443	552	508	34	875	846	859	34

8.3 Wood density and heartwood formation in larger wood samples from IFP

To more clearly and accurately determine the heartwood formation in Natapoa wood discs were cut at 3 three heights along the stem of 6 trees (Table 7). The total heights of sample trees ranged from 18.9m to 22.4m and diameter (DBH) ranged from 221-344 mm. The crown break, the point at which the first major branch is located was between 10-13.5m.

Table 7 Tree diameter, height and location of wood sampling from 6 trees harvested from IFP in 2012

					bottom- first log		top- first log		crown break	
tree number					ht m	mm	ht m	mm	ht m	mm
Sample	row	Tree	dbh	ht	Disc 1	ob	Disc 2	Ob	Disc 3	ob
1	2	5	320	20.5	1.3	320	6		12.5	
2	2	8	344	21.5	1.3	344	6	267	13.5	191
3	1	12	280	21.8	1.3	280	6	221	10.6	181
4	2	9	250	18.9	1.3	189	6	197	10	153
5	2	14	239	21.3	1.3	239	6	189	11	149
6	3	13	221	22.4	1.3	221	6	189	11	153

The more detailed study of wood samples cut from discs at 3 heights from 6 trees at IFP indicates variation in density between trees and wood density up the stem (Appendix 1). The wedges cut from the discs have a mean basic density of 470 kg/m^3, which is in keeping with the density of mature wood from the published literature. The air dried density (at 12% moisture content) for all the wedges was 535 kg/m^3 which compares to Thomson and Evans (2006) who reported a density of 530-540 kg/m^3 at a moisture content of 12%. The wood density from the 12 year old trees at IFP is similar in both cores and wedges (Table 8).

The proportion of heartwood in the larger wood samples reflected the results from the wood cores collected; whereby, the proportion of heartwood formation is extremely variable within sites (Table 8). In the IFP collection, the tree with the highest proportion of heartwood had over 52% of heartwood per volume of wood. Whilst the proportion of some of the samples is encouraging, two trees showed no obvious signs of heartwood formation or very little (3%). The IFP planting has captured a range of 14 provenances that show differences in terms of their heartwood formation. The literature into heartwood formation tends to indicate a very strong genetic component in the age and proportion of heartwood formation within species (Downes et al. 1997). However, the impact of site and water availability can also have a strong impact on the formation of heartwood (Chan et al. 2013).

Table 8 Basic Density and percentage of heartwood for 12 year old trees harvested at IFP (Site 1)

IFP Harvested trees

Tree number	DBH mm	Basic density BD*	Green density*	% Heartwood**
1	320	505	828	15
2	344	456	963	47
3	280	485	875	3
4	250	493	862	52
5	239	434	910	32
6	221	448	762	0
Avg	276	470	867	25

*Density = kg per cubic metre of wood

**Heartwood as a percentage of stem wood volume at breast height

The formation of heartwood is particularly important for species such as Natapoa, where wood is used for furniture and joinery, as wood colour will be an important factor in market acceptance. The variation in wood colour and absence of heartwood in the 12 year old trees may reduce their market value considerably (Figure 18). Therefore, it would be important to have the degree of heartwood formation be key criteria for any selection programs for commercial growers or a plantation industry. The variation in heartwood formation in both wood cores and the harvested trees from IFP indicates that it may be possible to select trees for breeding programs that have a larger proportion of heartwood.

Figure 18 Colour difference between the sapwood and the heartwood (dark brown) from the logs cut from IFP (left) and the variation.

8.3.1 Wood density larger wood sample processed from harvested trees at IFP.

The wood samples cut from the billets sawn from the harvested trees had a mean basic density of 525 kgm3. The air dried density of this batch of 22 wood samples was higher than the published data for the species at 592 kg/m3, compared to 535 kg/m^3 for the wedges.

8.4 Extension materials for landholders

A poster has been created to promote the use of Natapoa as a timber tree in mixed species plantations and agroforestry systems (Figure 19). The results from the ACIAR mixed species trials which include Natapoa have been presented in Vanuatu and a scientific pater is to be written on the mixtures for International Forestry Review later in 2013.

Figure 19 Extension poster on growing Natapoa in timber plantations.

9 Impacts

This small research activity has provided an important contribution to the use of lessor known multi-purpose trees in plantations. Natapoa has much to offer farm forestry growers as a high value timber tree, as well as producing nuts and fuel. The results of this activity indicate that the wood is similar to the wood of mature trees; however, there are some issues of concern for the species, particularly insect damage that can reduce wood quality.

9.1 Scientific impacts now and in 5 years

The main scientific impact of the research is to provide an assessment of the diameter growth and the wood density for this promising species. Whilst there has been support for planting this species more widely, the rates of growth and the fundamental properties of the wood remained unknown. This research has identified that Natapoa (Terminalia catappa) grows relatively quickly, at 2-2.5 cm in diameter to year 12. The early plantings also are producing trees with wood that is close that of mature wood (wood basic density at 8-12 years of 400- 470 kg/m^3). The air dried density (at 12% moisture content) for all the wedges was 535 kg/m^3 which compares to Thomson and Evans (2006) who reported a density of 530-540 kg/m^3 at a moisture content of 12%. The wood density tends to increase with age from 8 to 12 years and wood density tends to increase from the pith to the bark in younger trees. Wood density tended to show relationships across sites however, the colour of the wood and the formation of heartwood is extremely variable, both within sites and across age classes.

Another key scientific impact arising from the research undertaken in this project is to highlight the need to understand the risks posed by the shoot borers. These pests are a serious threat to the success of planting Natapoa and may have impacts on the w.

9.2 Capacity impacts now and in 5 years

This activity has provided some capacity-building impact for the staff of Vanuatu Department of Forests and landholders growing this species. The collection and processing of the wood samples has resulted in a change in the knowledge and skills of individuals (particularly those in the partner country). The participation in the sampling program will be of benefit to VDoF staff, providing an understanding of how to undertake a low impact wood properties assessment. The capacity building that occurred through their participation in the project and its training elements will be followed up in the ACIAR Whitewood Project. For the impact to be fully realised, the participants have the potential to use the new knowledge and skills in areas outside the scope of this project.

9.3 Community impacts now and in 5 years

A community impact arising from this SRA is the promotion of an agroforestry species that has timber value, environmental benefits, and traditional medicine and food production.

9.3.1 Economic impacts

Economic impacts arising from the project activities are to support the development of a key multi-purpose tree native to the Pacific region. The planting of this species has the potential to enhance an individual’s, a community’s or a country’s monetary wellbeing. The well designed and maintained planting of Natapoa may result in an economic impact that would be of direct benefit to farmer families:

• adopting a new crop variety that has a range of benefits that can be used locally or sold into markets;

• planting of this species can assist in the more efficient use of resources, through the production of food, medicines and timber from the one species.

9.3.2 Social impacts

The social impacts from these project activities have some potential to result in changes in health of an individual or community. The provision of local food and medicines has a health benefit to the local community. The provision of fuel and timber also has the potential to enhance the health and wellbeing of an individual or community.

9.3.3 Environmental impacts

Environmental impacts of larger- scale plantings of Natapoa are primarily the improvements in soil and water quality that arise from well considered tree planting. The planting of the species has some carbon sequestration benefits and can enhance biodiversity.

This species is particularly adaptable; it can grow on coastlines and protect fragile environments from the impacts of storms or saltwater intrusions.

9.4 Communication and dissemination activities

In this project the activities undertaken have been presented at 3 ACIAR workshops in Vanuatu. There is a broader interest in multi-purpose agroforestry and food security in the project that is of interest to Governments and NGOs.

10 Conclusions and recommendations

10.1 Conclusions

Natapoa is a species that has many important traditional uses, but has not been widely studied. This species has proved to be capable of rapid growth in well managed plantations and is producing wood that has properties that are sought after by processors and communities. The productivity of the young plantings that have been assessed in this project are encouraging, however, there are some issues regarding insect damage and the formation of heartwood that need further investigation.

10.2 Recommendations

In assessing the future needs for the development of this species, ACIAR could undertake to continue the research and development on both the food and timber qualities of this important tropical tree. The key recommendations from this project are:

- To carry out more detailed assessment of the wood properties of this species to select provenances that have the vigour and heartwood formation qualities that will generate high value timber for processors;
- To continue to monitor the impacts of the shoot borer on the young plantings across Vanuatu.
- To promote this species in other parts of the Pacific where the food and timber benefits could be realised and production of larger timber volumes could provide a larger scale resource to markets.

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12 Appendixes

12.1 Appendix 1: Wood properties table from harvested trees from IFP

IFP **Natapoa** Wedges

Tree	sample	height	grn weight	grn vol	radius	sap	wt 27.11.12	12/03/2013 ODW	BDD		Mean	Volume % heartwood
	1.01	1.3	120.87	139.46	13.0	7.8	95.64	84.34	605	outer		
	1.02	1.3	24.8	25.37			13.02	11.47	452	inner		
	1.21	6.0	113.7	153.19	12.0		83.98	74.19	484	both		
	1.22	6.0	175.9	219.02			130.03	114.84	524	both		
	1.30	12.5	111.3	148.34	7.5		76.89	68	458	both	505	40%
2	2.00	1.3	208.9	211.56	16.4	6.5	116.38	102.32	484	both		
	2.01	1.3	106.8	109.72			63.17	55.69	508	outer		
	2.02	1.3	112.4	98.98			53.43	46.94	474	inner		
	2.11	6.0	141.9	148.83	12.6	6.3	78.45	69.23	465	both		
	2.12	6.0	87	100.83			54.88	48.49	481	outer		
	2.13	6.0	38.7	36.9			14.98	13.17	357	inner		
	2.30	13.5	139.4	178.28			86.13	76.07	427	both	456	47%
3	3.01	1.3	178.1	193.57	12.3	9.9	115.59	101.65	525	both		
	3.02	1.3	151.9	171.47			103.31	91.21	532	outer		
	3.03	1.3	4.9	4.96			2.54	2.25	454	inner		
	3.10	6.0	221.9	278.35	10.8		149.26	132	474	both		
	3.20	10.5	216.8	276.76			137.7	121.69	440	both	485	3%
4	4.01	1.3	139.6	150.92	11.7	3.1	89.64	78.75	522	both		
	4.02	1.3	95.8	111.71			75.11	66.29	593	outer		
	4.03	1.3	117.1	118.94			63.81	55.92	470	inner		
	4.11	6.0	82.7	90.19	8.5	2.3	49.9	44.0	488	both		
	4.12	6.0	54.6	66.17			44.02	38.92	588	outer		
	4.13	6.0	38.8	50.29			21.14	18.62	370	inner		
	4.30	10.0	116.2	154.65	8.2		73.58	65.09	421	both	493	52%
5	5.01	1.3	157.5	153.47	10.1	4.9	80.6	71.1	463	both		
	5.02	1.3	95.8	101.61			58.85	51.97	511	outer		
	5.03	1.3	53.5	48.68			22.28	19.63	403	inner		
	5.10	6.0	190.9	240.12			109.12	96.45	402	both		
	5.20	10.0	94.9	137.66			60.67	53.78	391	both	434	32%
6	6.00	1.3	224.1	258.97		all	152.03	134.12	518	both		
	6.20	6.0	118	161.93		all	77.36	68.6	424	both		
	6.30	11.0	103.7	149.8		all	68.01	60.24	402	both	448	0%
									472			